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Research Article

Promoting young children's creativity via reverse engineering pedagogy in STEM education

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Creativity is a core element of children's development, particularly in early childhood education. In this study, the reverse engineering pedagogy was applied to preschool STEM education, with the aim of exploring the effects of reverse engineering pedagogy and project-based pedagogy on the cultivation of young children's creativity in preschool STEM education. A quasi-experimental study that utilized a non-equivalent groups design was conducted with 60 young children (age 4-5) from the middle classes of two kindergartens, comprising a control group who received the PBP intervention, and a group who received the reverse engineering pedagogy intervention. Creative self-efficacy, Torrance Tests of Creative Thinking Figural were conducted to evaluate young children's creativity. In addition, independent samples *t*-test, analysis of covariance and post hoc test were used to analyze the data to determine whether REP could improve young children's creativity better than project-based pedagogy. The results indicated significant improvements in young children's creative self-efficacy and creative thinking following the reverse engineering pedagogy intervention. The research findings highlight the value of reverse engineering pedagogy in preschool STEM education, especially in cultivating creativity.

Keywords: Pedagogical approach; Preschool STEM education; Project-based learning; Reverse engineering pedagogy

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1. Introduction

In the context of the Fourth Industrial Revolution [IR4.0], the education sector has been actively responding by transforming teaching practices under the guidance of 21st-century core competencies, among which creativity is widely regarded as one of the essential skills future citizens must possess (Aguilera & Ortiz-Revilla, 2021). Research indicates that creativity aims to cultivate creative thinking, enabling individuals to generate unique solutions in complex situations (Samaniego et al., 2024). As a result, it is regarded by organizations as a key factor in enhancing competitiveness and employability (Caniëls et al., 2022). Therefore, many countries have made the cultivation of creative thinking an important task in modern education (Wang & Burdina, 2024), and identify it as a fundamental learning aim within their education systems (Korean Ministry of Education, 2018; Singapore Ministry of Education, 2015). Although the intersection of creativity and education has attracted increasing scholarly attention (Hernández-Torrano & Ibrayeva, 2020;

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Marquis & Henderson, 2015), data from the Programme for international student assessment [PISA] shows that "less than 7% of students were able to autonomously and creatively apply scientific knowledge to unfamiliar problems" (Organisation for Economic Co-operation and Development [OECD], 2019). Therefore, fostering K-12 students' creativity is still an important issue that warrants continuous attention.

Currently, as an interdisciplinary approach of teaching that integrates science, technology, engineering, and mathematics, STEM education is widely recognized for its potential to foster students' creativity (Aguilera & Ortiz-Revilla, 2021; Gürsoy et al., 2023; Kholifah et al., 2018; Maskur et al., 2022; Üret & Ceylan, 2021). However, current research on STEM education goals mostly focuses on engagement and career choice, while paying insufficient attention to the development of twenty-first century competencies (Halawa et al., 2024). Under such an orientation, teachers tend to perceive the enhancement of creativity through STEM education as an inherent outcome, which in turn leads to insufficient attention. Moreover, many STEM programs tend to prioritize technical knowledge and standardized outcomes, which may inadvertently limit creative exploration, especially for younger learners (Harris & De Bruin, 2018). In early childhood STEM education, Li et al. (2022) found that most STEM activities focus on cognitive acquisition, offering limited opportunities for divergent thinking. It has been demonstrated that what truly drives STEM innovation is pedagogy rather than technology (Tan et al., 2019). Therefore, adjusting teaching strategies is a good choice to promote learners' creativity (Beruin, 2023; Zhong et al., 2021).

The Reverse Engineering Pedagogy [REP], an approach that employs the concept of reverse engineering in educational contexts. Due to its emphasis on starting with existing products rather than designing from scratch, Reverse Engineering Pedagogy has attracted increasing attention in the field of STEM education. Different from traditional project-based pedagogy [PBP], REP encourages learners to begin with a complete artifact, analyze its structure and function, deconstruct and reassemble it, and ultimately engage in redesign or incremental innovation. This process is believed to promote deeper cognitive engagement, which in turn has a positive impact on K-12 students' creativity (Zhong et al., 2024; Zhong et al., 2021). By comparison, existing studies on Reverse Engineering Pedagogy have largely concentrated on its role in enhancing learning enthusiasm (Liu et al., 2023), learning experiences (Kang, 2020), cultural understanding and cultural identity (Lin et al., 2024) ， engineering thinking (Rui, 2022; Zhan et al., 2024) as well as problem-solving abilities (López et al., 2019). Although the potential of Reverse Engineering Pedagogy has been widely recognized, there remains a significant gap in how REP influences creativity among K–12 students, particularly in the field of early childhood education, where related research is even more limited (Kang, 2020; Zhang, 2024). In fact, the development of individual creativity skills depends on early childhood cultivation (Üret & Ceylan, 2021), with the preschool stage being considered the golden age for creativity (Alfonso-Benlliure et al., 2013).

Therefore, this study aims to explore the effect of Reverse Engineering Pedagogy on fostering creativity in early childhood STEM education. Given that project-based pedagogy is one of the most widely employed approaches in STEM education, this study will use it as the control group, with REP as the experimental group. The study aims to explore whether implementing REP in STEM education can enhance young children's creativity more effectively than PBP. The findings are expected to validate the use of REP in preschool STEM settings, offer new directions and practical support for STEM teaching, and provide feasible strategies for fostering creativity.

2. Literature Review

2.1. Creativity

Creativity is widely defined as the ability to generate ideas, products, or solutions that are novel, surprising, and valuable (Kanematsu & Barry, 2016; Neville, 2024). It is a complex and multifaceted concept, and its definition has evolved from a unidimensional to a multidimensional construct (Cropley et al., 2019). In addition to individual traits, it also involves the interaction of

multiple factors, including cognitive processes, environmental influences, and social context (Sternberg, 2011). Driven by an interest in the cognitive processes underlying creativity, Guilford conceptualized creativity as comprising four elements, namely 1) Fluency: An individual's ability to produce a large number of ideas or solutions quickly and easily. 2) Flexibility: An individual's ability to consider various approaches and shift perspectives in problem-solving. 3) Originality: An individual's ability to generate unique and uncommon ideas that are novel and unexpected. 4) Elaboration: An individual's ability to develop and refine ideas in detail, expanding on initial thoughts (Guilford, 1950). According to Guilford's creativity theory, Torrance (1966) developed the Torrance Tests of Creative Thinking [TTCT], providing a reliable tool for identifying and nurturing learners' creative potential (Aranguren, 2014; Kim, 2006). Scholars Rhodes later broadened this perspective by introducing the "4 Ps of Creativity," an integrative framework that includes environmental and contextual dimensions (Rhodes, 1961). It consists of four components: 1) Person, which refers to the creator's behavior, personality, quality, and self-perception; 2) Process, which refers to the cognitive processes, such as motivation and divergent thinking, and problem-solving strategies; 3) Product, which refers to the tangible outcomes of the creative process, such as artworks, inventions, or any creative works. and 4) Press, which refers to the influence of the environment on the creator. As research deepens, scholars have found that the levels and forms of creativity need to be further refined to meet the diverse needs of education, work, and daily life. To this end, (Kaufman & Beghetto, 2009) expanded the traditional dichotomy between everyday creativity ("little C") and exceptional creativity ("big C") by introducing two additional levels: "mini-C" and "Pro-C", and proposed the "4C model of creativity" from a developmental perspective，namely 1）Mini-c: Creativity inherent in the learning process；2）Little-c: Everyday creativity found in nearly all people； 3）Pro-c: Professional-level expertise in any creative area, representing a developmental progression beyond little-c 4）Big-C: Eminent creativity, reserved for the great and historically significant contributions. This developmental perspective suggests that creativity is not an innate, sudden gift, but rather a skill that can be gradually nurtured in specific contexts. For this reason, there is an increasing consensus in academia that creativity can be cultivated (Kaufman & Sternberg, 2010), with schools being a key environment for its development.

The intersection of creativity and education plays a key role in personal development, adapting to the demands of an increasingly dynamic world while also meeting personal growth expectations (Craft, 2002; Hernández-Torrano & Ibrayeva, 2020; Kaufman et al., 2016; Marquis & Henderson, 2015). In an educational context, creativity is defined as the ability to generate original ideas and projects, with an emphasis on individual originality (Kanematsu & Barry, 2016; McLean et al., 2023). It is typically manifested in higher-level thinking, creative expression, creative problem solving, and knowledge construction, and can be integrated into multiple subject areas such as science, technology, engineering, and mathematics [STEM]. Creativity is considered a core human trait that promotes personal growth and development (Plucker, 2011). However, recent reports indicate that students' actual creativity levels still fall short of educators' expectations (OECD, 2019), highlighting that effective pedagogical framework remain inadequate.

2.2. Reverse Engineering Pedagogy

Reverse engineering originated during World War II and made significant contributions to the construction of military equipment such as aircraft and tanks. Initially, most researchers regarded it as a technical means (Zhang, 2024). Therefore, reverse engineering is understood as the process of analyzing and simulating existing products using modern technology, ultimately developing more advanced products through this technical means. Gradually, reverse engineering has evolved to be regarded as a teaching content in technical courses, such as software engineering, 3D printing, computer science, and robotic education courses. In recent years, many researchers have applied reverse engineering as a teaching approach in various professional fields. The reverse engineering pedagogy is seen as a teaching approach that starts from the finished product and

follows the "doing—learning—teaching" model (Kang & Zhong, 2020; Zhang, 2024). In a study, the best way to evaluate the appropriateness of a teaching approach is to apply it to practical teaching and analyze the learning effects. Therefore, scholars are actively putting reverse engineering pedagogy into practice.

Through a review of the literature, it can be found that the application of reverse engineering pedagogy in the field of education has achieved positive learning effects, especially in the context of robot education. The results show that in robotic education, the reverse engineering pedagogy not only enhances learners' learning engagement, motivation, and ability (Kang & Zhong, 2020), creativity (Yang, 2022; Zhong et al., 2021), understanding of scientific concepts (Chambers et al., 2008), and product optimization (Yang, 2022), but also reduces cognitive load (Zhong et al., 2024). Then some researchers have focused on the impact of reverse engineering pedagogy on engineering education. Research confirmed that reverse engineering pedagogy are beneficial for advancing learners' cognitive development and comprehensive application skills, expressive desire, and micro-innovative ability, especially innovative thinking and innovative skills, in software engineering, 3D printing, and computer science course (Yuan, 2023; Zhang, 2024). Moreover, some researchers have applied reverse engineering pedagogy to K12 STEM education, and findings from practical applications show that reverse engineering pedagogy are beneficial for enhancing students' enthusiasm for learning and expressive abilities (Liu et al., 2023), engineering thinking (Lin et al., 2024; Rui, 2022), creative thinking, as well as cultural understanding and cultural identity (Lin et al., 2024).

On the whole, as an emerging teaching approach in STEM education, Reverse Engineering Pedagogy has demonstrated certain benefits in multiple case studies across different fields, but it is still insufficient (Zhong et al., 2024). It is evident that the current verification of its effects is mainly concentrated in engineering-related fields. However, as an emerging approach in K–12 STEM education, less attention has been paid to its impact (Kang & Zhong, 2020; Zhang, 2024; Zhong et al., 2024). This study argues that, compared with its application in robotics or primary education, reverse engineering pedagogy is more compatible with preschool STEM education. Because disassembling and reassembling objects align with young children's natural tendencies, the logical sequence emphasized in REP—from understanding a prototype, to reproducing it, and ultimately to transcending it—places less emphasis on precise replication in preschool STEM contexts. Instead, it focuses on guiding young children to observe internal structures and engage in creative reassembly, thereby laying a foundation for the development of logical thinking.

3. Research Questions and Hypotheses

The importance of fostering creativity among K–12 students is widely recognized, but their creativity still falls short of expectations (OECD, 2019). STEM education contributes to the development of students' creativity. However, teachers regard the fostering of creativity through STEM education as a natural outcome, and therefore do not give it enough attention. Therefore, this study adjusts the traditional pedagogical approach in STEM education by adopting Reverse Engineering Pedagogy to explore its applicability and effectiveness in promoting the development of children's creativity. To gain a more comprehensive understanding of the development of individual creativity, this study selects creative self-efficacy and creative thinking as key indicators for measuring young children's creativity. So, this study aimed to answer the following research question, Does reverse engineering pedagogy promote young children's creativity better than project-based pedagogy? Specifically, the following three hypotheses were proposed accordingly:

H_1. REP can improve young children's creativity self-efficacy better than-PBP.

H_2. REP can improve young children's creativity thinking better than PBP.

4. Method

4.1. Research Design

As this is the first time that reverse engineering being integrated into preschool STEM education, we decided to set up a pilot study (Study 1) before taking out the formal experiment (Study 2). Both studies adopted a quasi-experimental design and compare the effect of project-based pedagogy and Reverse Engineering Pedagogy. Both studies used the same measurement instruments, but the procedure in Study 2 are revised according to the reflection from Study 1.

4.2. Pilot Study

A total of 30 young children coming from a kindergarten in South China participated in the pilot study. Among them, 16 young children (7boys and 9 girls) were assigned to the project-based groups and the other 14 students (7 boys and 7 girls) were assigned to the reverse-engineering groups.

The experiment in the pilot study lasted for 4 weeks, and every week was assigned two sessions for 30 min. Prior to the pilot study, the young children's prior knowledge of energy transformation was assessed to guide the design of the learning activities. After that, a 2-week wax melting lamp STEM activity was arranged using a real lamp, which is related to energy conversion. Every young child was surveyed on their prior knowledge after the completion of project. Table 1 shows the experimental schedule and learning contents of the PBP and REP eco-STEM wax melting lamp in the pilot study.

Table 1
Schedule of the experiment in pilot study

Class hour	*The Vision of an Energy-Efficient Home-Wax Melting Lamp Lesson plan*	
	PBP intervention	REP intervention
1st	Prior knowledge pretest	
2nd	Guide children to *observe* the wax melting lamp and record the changes that occur.	Observe the changes in a melting wax lamp and *deconstruct and reconstruct* it.
3–4th	*explain* to the children how *the heat affects the shape* of the wax.	Discuss what the natural drooping shape of the melting wax lamp resembles, allowing children to *seek answers in nature*.
5–6th	Encourage them to *design and construct* their own *wax melting lamp*	*Extract biomimetic characteristics* from natural objects to recreate
7th	engage in *sharing*	*share* the melting wax lamp.

After the pilot study, based on our reflections on the teaching process, we concluded: (1) The STEM products parts are too complex for young children, thus the alternative crafts need to be carefully chosen again that are easy for young children to dissect, (2) the learning group is adjusted from every six young children to every four children per group, and (3) the product record forms were provided to help young children observe and measure.

4.3. The Formal Study

The experiment for this study coincided with Energy Conservation Week in China. Therefore, the STEM activity theme was determined to be energy saving, and the activities focused on the imagination of energy-saving homes. The formal experiment was carried out in an eco-STEM activity in another Kindergarten of Chaozhou for 8 weeks from June 10, 2025 to August 10, 2025. Considering the rapid developmental changes characteristic of preschool age, the middle class is considered a golden period for educational intervention. Therefore, with the informed consent of parents and the voluntary participation of children, one class aged 4–5 years was assigned the PBP as the control group (N = 30, 14 boys and 16 girls), and based on their characteristics, the other one assigned by simple random sampling the reverse- engineering pedagogy as the treatment group

(N = 30, 17 boys and 13 girls). Prior to the experiment, four preschool teachers with middle titles, 3-5 years of experience, and undergraduate degrees conducted the prior knowledge quiz of children who had participated in STEM activities. the independent samples t-test results showed no significant difference among the two classes on the prior knowledge (p = .566 > .05), indicating basically equal starting levels.

4.3.1. Procedure

In this experiment, the same research design was used: the control group adopted PBP while the experimental group adopted REP. In the first week, four lead and assistant teachers measured the environmental awareness, creativity self-efficacy, and STEM learning attitudes of 60 young children. From the second to the tenth week, the young children were required to design, build, and optimize their own Energy-Efficient Home. The control group adhered to adopted PBP, while the experimental group adopted REP. To ensure that the young children gain sustained experiences through these activities, we will conduct at least one activity each week., each activity will be divided into varied tasks based on the level of difficulty of the content. This arrangement not only allows young children to focus their attention for a shorter period of time but also effectively promotes their learning and understanding. The specific weekly lesson plan will be detailed, outlining the themes, objectives, content, and implementation steps of the activities to ensure that each session achieves the intended educational outcomes. The detailed weekly lesson plan for the kindergarten eco-STEM practice is presented in Table 2.

Table 2
Weekly lesson plans for energy-saving home eco-STEM activities

Week index	*Lesson plan: The Vision of an Energy-Efficient Home*	
Week 1	Conducting pre-experimental assessments on prior knowledge	
	FPP intervention	REP intervention
Week 2-4	Project 1: Eco-Friendly Water Clock Emphasizing the importance of *water resources* and encourage children to explore the principles of how the water clock works. Then, explain the principles and have them try to make one. Finally, create posters promoting water conservation to deepen children's understanding	Using a water clock to record one's daily life and then deconstructing and reconstructing it allows one to feel the passage of time in nature. Extracting biomimetic elements to serve as the hour hand, minute hand, and second hand enables the recreation and sharing of the water clock.
Week 5-7	Project #2: Energy-Efficient Fan Discuss the challenges of electricity shortages caused by soil erosion and encourages children to explore the principles of how handmade energy-saving fan works. Then, explain the principles to them and have them attempt to make one. Finally, engage in sharing.	Play with a handmade fan and then deconstruct and reconstruct it. Discuss how animals and plants cool themselves, allowing children to seek answers in nature. Extract biomimetic characteristics from natural objects to recreate and share the fan.
Week 8	Conducting post-experimental assessments on children's prior knowledge and environmental awareness, creativity self-efficacy, and STEM learning attitudes.	

4.3.2. Intervention

In the study, the PBP intervention referring to the 6E teaching model proposed by Burke (2014) including Engage, Explore, Explain, Engineer, Enrich, and Evaluate. Specifically, in the PBP group, the teacher first introduced the issue of electricity shortages caused by soil erosion through a video and guided the children to explore in groups of four young children, and provides a

product record sheet. Following this, the teacher then explained the energy-saving fan through an experiment. Based on the knowledge they have gained, the children were asked to design and construct an energy-saving fan and to build the most robust "house" capable of withstanding soil erosion after heavy rainfall. After the activity, the teacher guides young children in reflection, discussing what they learned during the activity, which designs were the most effective, and how improvements can be made in the future.

Figure 1
Participants in the PBP intervention

However, in the REP, as shown in Figure 2. The REP intervention refers to the structural model in the lantern model by Kang and Zhong (2020), which includes: experience and analysis, decomposition and restoration, redesign and micro-innovation, prototyping or re-engineering, and evaluation and reflection. Based on reflections from the pilot study, the materials used in subsequent activities were simplified, and a simpler fan that was easier to disassemble was selected. To be specific, young children begin with manipulating or playing with the fan demonstrated by the preschool teacher. Next, the young children will take apart the fan, complete a disassembly record form, and then reassemble the product to its original condition in groups of four children. When young children are asked to redesign their energy-saving fan, the teacher provides a supportive environmental experience, so that they can reasonably and practically carry out biomimetic design and re-produced. Once the energy-saving fan are completed, the young children need to compare with the previous products to evaluate the improvements and shortcomings in the design.

Figure 2
Participants in the REP intervention

4.3.3. Measures

As creativity is a complex construct that is influenced by multiple factors. According to Bronfenbrenner's ecological systems theory, Young children's development is directly influenced by microsystems (e.g., the family and the classroom). Within the family context, research has

consistently indicated that parental involvement generally has a positive correlation with student creativity (Fan et al., 2024). Similarly, within the classroom context, existing research has shown that a creative classroom climate significantly promotes students' creativity (Mikó et al., 2025). Therefore, to control for a priori differences that could affect the intervention's effectiveness, this study introduced family involvement and classroom atmosphere as covariates based on a pretest (creative self-efficacy and creative thinking). The Family Involvement Scale (4 items) was adapted from Epstein and Connors (1995) and Fantuzzo et al. (2000) and was used to assess parents' activeness in supporting learning and engaging with the school. The Classroom Atmosphere Scale (4 items) was adapted from Fraser (1998) and Trickett and Moos (1974), primarily measuring the interaction atmosphere within the classroom. Both scales use a 5-point Likert scale, with higher scores indicating better family involvement or classroom atmosphere. Given that creativity is inherently multidimensional, using a single assessment may be insufficient. Therefore, at least two measurements need to be adopted to evaluate young children' creativity (Kim, 2006). In this study, creative self-efficacy and the Torrance Tests of Creative Thinking were used to comprehensively evaluate young children's creativity. The instruments are described in more detail below.

Creative self-efficacy. Creative self-efficacy refers to an individual's belief in their ability to produce creative product (Tierney & Farmer, 2002). A young children's creative self-efficacy can help teachers better understand how young children perceive their own creative performance in eco-STEM product design. Referring to Zhong et al.'s (2021) questionnaire, it was designed nine questions from three dimensions (creative products, creative strategies, and individual feedback) to creative self-efficacy. Preschool teachers were asked to rate on a 5-point Likert-type scale with response options ranging from 1 (strongly disagree) to 5 (strongly agree). The creativity self-efficacy scale demonstrated high internal consistency, with a Cronbach's α of .92. Prior to formal scoring, the raters conducted preliminary scoring and discussions based on a small sample to calibrate their understanding of the scoring criteria. Subsequently, the creative self-efficacy questionnaire was formally scored for both the IG and CG groups. Results showed they reached good agreement with an intraclass correlation coefficient (ICC) > 0.85 (creative products=.88, creative strategies=.82, individual feedback=.90), meeting Koo and Li's (2016) criteria for "good agreement."

Creative Thinking. This study uses the Torrance Tests of Creative Thinking Figural Test to assess children's creative thinking. The TTCT, created by Torrance (1966), is a research tool used to evaluate creative thinking potential. The TTCT consists of two versions: verbal and figural, and is suitable for students from kindergarten to adulthood. Since the study focuses on young children, only the TTCT-Figural version is used for assessment in this research. The TTCT-Figural consists of three tasks: picture construction, picture completion, and repeated line drawings. According to the scoring instruction of the TTCT-Figural manual, four subscales including originality (act. 1, 2, 3), fluency (act. 2, 3), flexibility (act. 2, 3), and elaboration (act. 1, 2, 3) were the observed variables.

During the testing, the researchers conducted group assessments with no more than 15 young children per group. The young children were arranged in a quiet classroom for the evaluation, with each child assigned to an individual seat. The researcher read and explained each question to the young children, who then created drawings based on the task requirements. The researcher observed and provided timely assistance to the children. The assessment time for each task did not exceed 10 minutes. Due to the broad scoring requirements for creative thinking, this study aimed to ensure the reliability of the results. Therefore, before starting the scoring, the researchers and four research assistants familiarized with the TTCT-Figural scoring manual together and unified the scoring criteria through coordination meetings. Prior to the formal scoring, the study conducted a pilot scoring on five questionnaires, and the ICC (3,4) for the four dimensions all exceeded .82, indicating that the scorers had good consistency. The TTCT-Figural questionnaire was then formally scored for both the IG and CG groups. Results showed they reached good agreement with an intraclass correlation coefficient (ICC) > .89 (Originality = .84, Fluency = .86,

Flexibility = .80, and Elaboration = .89), meeting Koo and Li's (2016) criteria for "good agreement." The average of the four raters' scores was used as the final score on the TTCT-Figural questionnaire. Before summing the scores for each subscale to calculate the overall creativity score, the raw scores were first converted to T scores (Wu & Ding, 1998).

4.3.4. Data analysis

Data analysis in this study employed independent samples t-test, analysis of covariance [ANCOVA] and post hoc test to assess the intervention effects. To test whether there were significant differences between the CG (control group) and IG (experimental group) young children in terms of creative self-efficacy and creative thinking before the intervention, an independent samples t-test was conducted. And then, analysis of covariance was conducted (Hair et al., 2023), with pre-test scores, family involvement, and classroom atmosphere as covariates, and post-test scores as the dependent variable, to examine whether there are differences in intervention effects between PBP and REP. In ANCOVA analyses, partial eta squared (η^2) is reported as an indicator of effect size, values in the range of 0 ~ 0.05 are deemed small, between 0.06~0.14 are considered as medium, and 0.14 and higher are accepted as a large effect size (Cohen, 2016). Furthermore, a post-hoc test (LSD) was conducted to more accurately examine the direction of the intervention effect differences between PBP and REP. All statistical analyses were performed using SPSS 27.0 software.

4.3.5. Ethical considerations

This study adopted prior knowledge test and observation record scale to collect participants' data. Before conducting formal data collection, all parents or legal guardians of participants were informed of the study's purpose, content, and data collection procedures and that the data collected would be used for the sole purpose of the study. And assent was also obtained from children using age-appropriate language. The wishes of children were strictly respected during the research process, and it was made clear that children had the right to refuse to answer any questions or stop participating at any time. In addition, the researcher is fully aware that this study has the responsibility to protect the data obtained during the research. Therefore, all data are encoded using an anonymous method, and the findings reported must be in a real and complete way, and did not falsify or tamper with the results. The study adhered to the principles of the Helsinki Declaration and received approval from the Ethics Review Committee of Guangdong Chaozhou Health Vocational College (approval number: [CHVC20250608].

5. Study Results

5.1. Creative Self-efficacy

A similar level of creative self-efficacy was found between the CG and IG before the experiment (t = .388, p = .070 > .05), indicating that the initial conditions for both groups were essentially consistent. Then, parental involvement [PI], classroom climate [CC], and pretest scores served as covariates, while creative self-efficacy and its subdimensions (Creative product belief，Creative thinking strategies belief，Resisting negative feedback belief) were the dependent variables in a one-way analysis of covariance. As illustrated in Table 3，significant differences were observed in the creative self-efficacy scores of the CG and IG (F(4,55)=11.087, p = .002)，with a significantly large effect size（Partial η^2 =0.168）. Among these, the sub-dimension of creative product belief (F(4,55) = 9.261, p = .004) also reached a significant level and achieved a large effect size (partial η^2 = 0.144). However, creative thinking strategies belief (F = 0.219, p = .775) and resisting negative feedback belief (F = 0.013, p = .910) did were not significant.

Table 3
Creative Self-Efficacy ANCOVA Main Effects Analysis Results

Dependent Variable	*Covariate*	*ANCOVA F (df1, df2)*	*p*	*Partial η2*	*R²*
Posttest Creativity self-efficacy	PI, CC, Pretest Creativity self-efficacy	11.087 (1, 55)	.002*	0.168	0.127
Posttest creative product belief	PI, CC, Pretest creative product belief	9.261 (1, 55)	.004*	0.144	0.135
Posttest creative thinking strategies belief	PI, CC, Pretest creative thinking strategies belief	0.219 (1, 55)	.775	0.002	−0.056
Posttest resisting negative feedback belief	PI, CC, Pretest resisting negative feedback belief	0.013 (1, 55)	.910	0.000	−0.057

Note. *p < .05 indicates a significant difference.

Moreover, post-hoc LSD tests (see Table 4) revealed that the IG group scored significantly higher than the CG group in creativity self-efficacy (MD= −0.462, p = .002) and creative product belief (MD= −0.435, p = .004), whereas no significant differences were found between the two groups in creative thinking strategies belief and resisting negative feedback belief. Accordingly, the results indicated significant improvements in young children's creative self-efficacy and creative product beliefs following the REP intervention, while its effects on creative thinking strategy beliefs and resistance to negative feedback beliefs were limited.

Table 4
Creativity Self-Efficacy: Post Hoc Test Comparison Results Between IG and CG Groups

Dependent Variable	*IG mean*	*CG mean*	*Mean Difference (MD)*	*Standard Error (SE)*	*p*	*95% CI Lower Limit*	*95% CI Upper Limit*
Posttest Creativity self-efficacy	3.7523	3.2993	.462*	0.139	.002*	0.184	0.739
Posttest creative product belief	4.1230	3.6900	.435*	0.143	.004*	0.148	0.721
Posttest creative thinking strategies belief	3.2000	3.2447	−0.056	0.134	.775	−0.449	0.336
Posttest resisting negative feedback belief	3.0217	2.9997	0.020	0.171	.910	−0.324	0.363

5.2. Creative Thinking

Prior to the intervention, similar levels of creative thinking were observed in the IG and CG (t = −3.44, p =.732). Then, parent involvement, classroom climate, and pre-test scores were used as covariates, while creative thinking and its subdimensions (Fluency, Flexibility, Originality, Elaboration) served as dependent variables in a one-way analysis of covariance. As illustrated in Table 5，significant differences were observed in the creative thinking of the CG and IG（F(1,55) = 75.933, p < .001）, with a large effect size (Partial η^2 = 0.580). Among the sub-dimensions, Flexibility (F(4,55) = 4.902, p = .031, Partial η^2 = 0.082) and Originality (F(4,55) = 5.487, p = .023, Partial η^2 = 0.091) were both significant and reached medium effect sizes, Fluency (F(4,55) = 11.03, p = .002, Partial η^2 = 0.167) also showed a significant difference, characterized by a large effect size. In contrast, elaboration (F = 0.064, p = .802) did not reach statistical significance.

Table 5
Creative Thinking ANCOVA Main Effects Analysis Results

Dependent Variable	*Covariate*	*ANCOVA F (df1, df2)*	*p*	*Partial η2*	*R^2*
Posttest Creativity	PI, CC, Pretest Creativity	75.93 (1, 55)	< .001	0.580	0.607
Posttest Fluency	PI, CC, Pretest Fluency	11.03 (1, 55)	.002	0.167	0.130
Posttest Flexibility	PI, CC, Pretest Flexibility	4.902 (1,55)	.031	0.082	0.120
Posttest Originality	PI, CC, Pretest Originality	5.487 (1,55)	.023	0.091	0.060
Posttest Elaboration	PI, CC, Pretest Elaboration	0.064 (1,55)	.802	0.001	0.030

Note. *p < .05 indicates a significant difference.

As shown in Table 6, Post-hoc LSD tests further confirmed that the IG group demonstrated significantly greater creativity self-efficacy (MD = −0.462, p = .002), fluency (MD = 3.714, p = .002), flexibility (mean difference = 2.176, p = .031), and originality (MD = 6.783, p < .001) compared to CG group, while the difference in elaboration remained non-significant. Accordingly, the results indicated significant improvements in young children's creative thinking and subdimensions (particularly fluency, flexibility, and originality) following the REP intervention, but its impact on elaboration remains limited.

Table 6
Creative Thinking: Post Hoc Test Comparison Results Between IG and CG Groups

Dependent Variable	*IG mean*	*CG Mean*	*Mean Difference (MD)*	*Standard error (SE)*	*p*	*95% CI Lower Limit*	*95% CI Upper Limit*
Posttest Creativity	64.5773	57.7043	6.783*	0.778	<.001	5.223	8.342
Posttest Fluency	17.6886	14.1253	3.714*	1.118	.002	1.473	5.956
Posttest Flexibility	17.6200	15.3960	2.176*	0.983	.031	0.206	4.145
Posttest Originality	23.2967	22.1667	1.047*	0.447	.023	0.151	1.943
Posttest Elaboration	5.9720	6.0163	0.072	0.285	.802	-0.500	0.644

6. Discussions

The cultivation of creativity among K-12 students remains a worthy priority. In this context, numerous studies grounded in reverse engineering pedagogy tend to prioritize the measurement of creativity. This study indicates that IG young children scored significantly higher on overall creativity measures than CG young children, suggesting that REP intervention play a positive role in enhancing young children' s creativity. Our findings are inconsistent with the view that analyzing a complete product's functions and features may limit learners' creativity (Ladachart, 2022; Schut et al., 2020), but support previous research indicating that REP interventions have a positive impact on learners' creativity (Liu et al., 2023; Zhan et al.,2024; Zhong et al., 2021).

With further analysis, it was found that regarding Hypothesis 1, IG young children who received REP gained a higher level of creativity self-efficacy than CG young children who received PBP. Our findings support the studies by Atwood-Blaine et al. (2019), Liu et al. (2023), and Lin et al. (2024), which demonstrated a positive effect of REP intervention on the creative self-efficacy. However, in terms of the sub-dimension of creative self-efficacy, the results contrast with those of Zhong et al. (2021), which highlighted significant difference related to creative strategies and individual feedback in primary robotics education. This result can be explained by Piaget's theory of cognitive development. Children in early childhood education are still in the preoperational stage of cognitive development compared to students in elementary and secondary school, and

their thinking is irreversible. Consequently, they lack sufficient abstract thinking skills to comprehend and apply complex creative thinking strategies. This limitation also makes it difficult for them to objectively analyze negative feedback when confronted with it, leading to emotional reactions. Additionally, a relatively low level of psychological resilience in a child makes them more sensitive to negative external information and experiences of failure, while the impact of positive information is less pronounced.

In contrast, the REP group outperformed the PBP group in terms of creative products belief. This result can be explained by Bandura's theory of self-efficacy, which emphasizes mastery experiences as the primary source of self-efficacy beliefs (Zadorozhnyy, 2025). By providing young children with a comprehensible and complete product at the early stage of learning, REP creates early mastery experiences that enable young children to perceive completed product as achievable, thereby strengthening their beliefs in their own creativity. In brief, only the belief in creating new products demonstrated statistical significance within the sub-factors of creative self-efficacy, though the effect size was relatively small. This also implies that STEM practices guided by reverse engineering pedagogy may support improvements in young children's creative self-efficacy, particularly playing a crucial role in fostering their belief in creating refreshingly novel products. Short-term positive feedback has been shown to lead to changes in beliefs (Bandura, 1977).

Additionally, this study found that IG young children who received REP gained a higher level of creativity thinking than CG young children who received PBP, which confirmed Hypothesis 2. Our findings regarding the positive effect of REP intervention on primary school students' creative thinking in Robotics Education corroborate the existing researches (Lin et al., 2024; Liu et al., 2023; Parlak et al., 2024). The core difference between REP and PBP lies in their distinct learning processes. From the perspective of Bandura's theory of Goal Orientation, The CG students, unlike the children in PBL learning, typically do not need to confront undefined or open-ended problems alone. Instead, they engage in meaningful re-creation within meaningful contexts after thorough interaction with familiar objects, guided by learning objectives. Research indicates that learning goal orientation [LGO] can enhance the positive influence of intrinsic motivation on creativity (Kaspi-Baruch, 2018; You, 2021). What's more, individuals with a learning mindset are more likely to embrace challenges and persevere in the face of adversity, which is crucial for creative problem-solving.

It was found that within the REP intervention environment, fluency (idea quantity), flexibility (thinking diversity), and originality (idea novelty) improved. Liu et al.'s (2023) study supports our findings which demonstrated a positive effect of REP intervention on the fluent, flexible, and original ideas. However, the impact on elaboration (idea detail) was limited, after conducting a more in-depth analysis of the various sub-dimensions of creative thinking. The findings resonate with the result of Liu et al. (2023), showing that REP cannot provide ways for students to provide details of the ideas. Consistent with problem-finding theory, fact finding and problem finding have been found to be positively correlated with both the number of ideas produced and the originality of these ideas (Van Hooijdonk et al., 2020). Actually, REP is essentially a combined process of fact finding and problem finding. For example, in the learning topic titled "Energy-Saving Fan," a child gains fact-finding experience by disassembling and reassembling a fan to understand its operating principles and constituent parts. After completing the dissection, they further explored how plants and animals achieve self-cooling, thereby engaging in problem finding within the natural world. IG preschool children need to conduct fact-finding based on energy-saving fans, observing how different plants and animals cool themselves to extract biomimetic features from nature and redesign energy-saving fans. Ultimately sparked the creative thinking of IG children (Zhong et al., 2021).

For comparison, the REP group did not show significantly greater elaboration in creative thinking compared to the PBP group. This finding was consistent with previous research emphasizing the limited effectiveness of REP interventions in enhancing proficiency (Zhan et al., 2024). This result can be explained by Vygotsky's theory of self-regulation (Vygotsky, 1978), which

emphasizes the development of diligence depends on sustained attention, a capacity that has not yet fully matured in a child (Avetisyan et al., 2025). Furthermore, REP activities themselves are predominantly learning goal-oriented, placing greater emphasis on rapidly generating and experimenting with diverse ideas, while offering children fewer opportunities to repeatedly refine, elaborate, and expand upon a single idea. Taken together, improvements were shown across key subcomponents of creative thinking (i.e., fluency, flexibility, and originality), suggesting that REP may be more promising than PBP in stimulating young children's creative thinking in STEM education.

7. Conclusion and Implication

The present study explored the comparative effects of REP and PBP on young children's creativity in STEM education. with the results indicating that young children in the REP group demonstrated higher levels of creative self-efficacy and creative thinking than those in the PBP group. Theoretically, this study further demonstrates the feasibility of REP in cultivating creativity in STEM education. It is the first to introduce Reverse Engineering Pedagogy into preschool STEM education, constituting an academically innovative teaching experiment. Practically, this study clarifies the implementation pathway of Reverse Engineering Pedagogy in preschool STEM education, providing a feasible paradigm for future course design. This outcome is expected to promote greater emphasis on the application of Reverse Engineering Pedagogy in future preschool STEM education, offering new insights for teaching practice.

8. Limitations and Future Study

Firstly, due to the limited sample size and the lack of random assignment, the statistical power of this study was constrained, and variables that did not reach statistical significance—namely creative thinking strategies belief, resisting negative feedback belief, and elaboration—were therefore interpreted with caution. Although several strategies were adopted to mitigate these limitations, including rigorous homogeneous inclusion criteria, a matched quasi-experimental design, the use of sensitive measurement instruments (the Creative Self-Efficacy Scale and the Torrance Tests of Creative Thinking), the inclusion of pretest scores as covariates, and the control of meaningful covariates such as parental involvement and classroom climate, future studies with larger samples and randomized controlled designs are still needed to further validate the present findings. In addition, as the intervention was implemented by preschool teachers, potential teacher-related bias may have occurred, as teachers' expectations and emphases could have unintentionally influenced young children's learning effect.

Secondly, the Torrance Tests of Creative Thinking used in this study lack localized normative data for children under the age of 6. Therefore, only raw scores were used in the data analysis, which limits the comparison and interpretation of the results in broader populations and may also affect the assessment of the generalizability of the intervention's effects. Future research could consider promoting the development of normative data for this age group to enhance the standardization of score interpretation and the comparability of research findings. Finally, since the theoretical framework of this pedagogical approach is not yet fully developed, particularly regarding its adaptability to different age groups, further research is needed for continuous improvement and refinement.

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Data availability: All data are available from the corresponding author with reasonable request.

Declaration of interest: The authors declared that there were no potential conflicts of interest.

Ethical statement: The author (Peng Zhang) is currently pursuing a Ph.D degree at Universiti Kebangsaan Malaysia (UKM) while simultaneously serving as a teacher at Chaozhou Vocational College of Health, Guangdong, China. Since the research activities and data collection were primarily conducted in China, ethical approval for this study was required to be obtained from the relevant institutions within China. Therefore, the ethics statement of this research appropriately includes Chaozhou Vocational College of Health as the responsible institutional body for ethical clearance and research oversight.

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References

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A systematic literature review. *Education Sciences, 11*(7), 331. https://doi.org/10.3390/educsci11070331

Alfonso-Benlliure, V., Melendez, J. C., & Garcia-Ballesteros, M. (2013). Evaluation of a creativity intervention program for preschoolers. *Thinking Skills and Creativity, 10,* 112-120. https://doi.org/10.1016/j.tsc.2013.07.005

Aranguren, M. (2014). Construct validity of the Torrance Test of Creativite Thinking in Argentinean young adults. *Anuario de Psicología / The UB Journal of Psychology*, *44*(1), 55-70.

Atwood-Blaine, D., Rule, A. C., & Walker, J. (2019). Creative self-efficacy of children aged 9-14 in a science center using a situated Mobile game. *Thinking Skills Creativity Research Journal, 33*, 100580. https://doi.org/10.1016/j.tsc.2019.100580

Avetisyan, M., Stepanyan, N., & Konjoyan, H. (2025). Attention features in preschool and younger school age. *Main Issues of Pedagogy Psychology, 12*(1), 29-37. https://doi.org/10.24234/miopap.v12i1.65

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review, 84*(2), 191. https://doi.org/10.1037/0033-295X.84.2.191

Beruin, L. C. (2023). Learning privilege divide: A framework for interrogating personal privileges of STEM students' education during the pandemic. *Journal of Pedagogical Sociology and Psychology, 5*(4), 40-56. https://doi.org/10.33902/jpsp.202323515

Burke, B. N. (2014). The ITEEA 6E Learning byDeSIGN [TM] Model: maximizing informed design and inquiry in the integrative STEM classroom. *Technology Engineering Teacher, 73*(6), 14-20.

Caniëls, M. C., de Jong, J. P., & Sibbel, H. (2022). The curvilinear relation between work predictability and creativity. *Creativity Research Journal, 34*(3), 308-323. https://doi.org/10.1080/10400419.2021.1994204

Chambers, R., Lo, B. C. Y., & Allen, N. B. (2008). The impact of intensive mindfulness training on attentional control, cognitive style, and affect. *Cognitive Therapy Research, 32*(3), 303-322. https://doi.org/10.1007/s10608-007-9119-0

Cohen, J. (2016). A power primer. In A. E. Kazdin (Ed.), *Methodological issues and strategies in clinical research* (4th ed., pp. 279–284). American Psychological Association. https://doi.org/10.1037/14805-018

Craft, A. (2002). *Creativity and early years education*. Bloomsbury.

Cropley, D. H., Patston, T., Marrone, R. L., & Kaufman, J. C. (2019). Essential, unexceptional and universal: Teacher implicit beliefs of creativity. *Thinking Skills and Creativity, 34*, 100604. https://doi.org/10.1016/j.tsc.2019.100604

Epstein, J. L., & Connors, L. J. (1995). School and family partnerships in the middle grades. In B. Rutherford (Ed.), *Creating school/family partnerships* (Vol. 1, pp. 137-166). National Middle School Association.

Fan, H., Feng, Y., & Zhang, Y. (2024). Parental involvement and student creativity: a three-level meta-analysis. *Frontiers in Psychology*, *15*, 1407279. https://doi.org/10.3389/fpsyg.2024.1407279

Fantuzzo, J., Tighe, E., & Childs, S. (2000). Family involvement questionnaire: A multivariate assessment of family participation in early childhood education. *Journal of Educational Psychology, 92*(2), 367.

Fraser, B. J. (1998). Classroom environment instruments: Development, validity and applications. *Learning Environments Research, 1*(1), 7-34.

Guilford, J. P. (1950). Creativity. *American Psychologist, 5*(9), 444–454. https://doi.org/10.1037/h0063487

Gürsoy, K., Bebek, G., & Bülbül, S. (2023). The effect of STEM education practices on academic achievement and scientific process skills: A meta-analysis study. *Journal of Pedagogical Sociology and Psychology, 5*(3), 221-246. https://doi.org/10.33902/jpsp.202324071

Hair, J. F., Sarstedt, M., Ringle, C. M., & Gudergan, S. P. (2023). *Advanced issues in partial least squares structural equation modeling*. Sage.

Halawa, S., Lin, T.-C., & Hsu, Y.-S. (2024). Exploring instructional design in K-12 STEM education: a systematic literature review. *International Journal of STEM Education, 11*(1), 43. https://doi.org/10.1186/s40594-024-00503-5

Harris, A., & De Bruin, L. R. (2018). Secondary school creativity, teacher practice and STEAM education: An international study. *Journal of Educational Change, 19*(2), 153-179. https://doi.org/10.1007/s10833-017-9311-2

Hernández-Torrano, D., & Ibrayeva, L. (2020). Creativity and education: A bibliometric mapping of the research literature (1975–2019). *Thinking Skills and Creativity, 35*, 100625. https://doi.org/10.1016/j.tsc.2019.100625

Kanematsu, H., & Barry, D. M. (2016). *STEM and ICT education in intelligent environments* (Vol. 91). Springer International Publishing.

Kang, S. (2020). *Research on the effectiveness of reverse engineering teaching methods in robotics education* [Unpublished master's thesis]. NanJing Normal University.

Kang, S., & Zhong, B. (2020). Case design and implementation of structural innovation teaching model in robotics education. *Journal of Curriculum and Instruction, 01*, 75-81.

Kaspi-Baruch, O. (2018). Difference between motivational goal framing effects on creative and perceptual task performance. *Creativity Studies, 11*(2), 294-310. https://doi.org/10.3846/cs.2018.3074

Kaufman, J. C., Beghetto, R. A., & Dilley, A. (2016). Understanding creativity in the schools. In A. A. Lipnevich, F. Preckel, & R. D. Roberts (Eds.), *Psychosocial skills and school systems in the 21st century: Theory, research, and practice* (pp. 133–153). Springer International Publishing/Springer Nature.

Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The four-c model of creativity. *Review of General Psychology*, *13*(1), 1-12. https://doi.org/10.1037/a0013688

Kaufman, J. C., & Sternberg, R. J. (2010). *The Cambridge handbook of creativity*: Cambridge University Press.

Kholifah, I. N., Maryanto, A., & Widodo, E. (2018). Pengaruh pembelajaran IPA berbasis STEM terhadap sikap ingin tahu dan keterampilan berpikir kreatif peserta didik SMP. *E-Journal Pendidikan IPA, 7*(3), 129135.

Kim, K. H. (2006). Can we trust creativity tests? A review of the Torrance Tests of Creative Thinking (TTCT). *Creativity Research Journal*, *18*(1), 3-14. https://doi.org/10.1207/s15326934crj1801_2

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Korean Ministry of Education. (2018). New textbooks for the 2015 national curriculum. https://english.moe.go.kr/boardCnts/viewRenewal.do?boardID=265&boardSeq=73479&lev=0&statusYN=C&s=english&m=0201&opType=N

Ladachart, L., Cholsin, J., Kwanpet, S., Teerapanpong, R., Dessi, A., Phuangsuwan, L., & Phothong, W. (2022). Ninth-grade students' perceptions on the design-thinking mindset in the context of reverse engineering. *International Journal of Technology and Design Education*, *32*(5), 2445-2465. https://doi.org/10.1007/s10798-021-09701-6

Lin, Z., Zhan, Z., & Zhang, H. (2024). Exploring the effectiveness of reverse engineering pedagogy in a culture-oriented STEAM course: From heritage to creativity. *Social Education Research*, *5*(1), 128-151. https://doi.org/10.37256/ser.5120243559

Liu, X., Gu, J., & Zhao, L. (2023). Promoting primary school students' creativity via reverse engineering pedagogy in robotics education. *Thinking Skills Creativity Research Journal, 49*, 101339. https://doi.org/10.1016/j.tsc.2023.101339

Liu, X., Wang, X., Xu, K., & Hu, X. (2023). Effect of reverse engineering pedagogy on primary school students' computational thinking skills in STEM learning activities. *Journal of Intelligence*, *11*(2), 36. https://doi.org/10.3390/jintelligence11020036

López, E. J., Flores, M. A., Sandoval, G. L., Velázquez, B. L., Vázquez, J. J. D., & Velásquez, L. A. G. (2019). Reverse engineering and straightforward design as tools to improve the teaching of mechanical engineering. In M. Abdulwahed, A. Bouras & L. Veillard (Eds.), *Industry Integrated Engineering and Computing Education: Advances, Cases, Frameworks, and Toolkits for Implementation* (pp. 93-118): *Springer*.

Marquis, E., & Henderson, J. A. (2015). Teaching creativity across disciplines at Ontario universities. *Canadian Journal of Higher Education, 45*(1), 148-166. https://doi.org/10.47678/cjhe.v45i1.184340

Maskur, R., Suherman, S., Andari, T., Sri Anggoro, B., Muhammad, R. R., & Untari, E. (2022). The Comparison of STEM approach and SSCS learning model for secondary school-based on K-13

curriculum: The impact on creative and critical thinking ability. *Revista De Educación a Distancia (RED), 22*(70), 2-31. https://doi.org/10.6018/red.507701

McLean, N., Georgiou, H., Matruglio, E., Turney, A., Gardiner, P., Jones, P., et al. (2023). Understanding creativity in primary English, science, and history. *The Australian Educational Researcher, 50*(2), 581-600. https://doi.org/10.1007/s13384-021-00501-4

Mikó, A., Karsai, I., & Kovács, K. (2025). The impact of creative educational climate on the choreography of fundamental movement sequences. *Creativity: Theories – Research – Applications, 12*(1), 121-138. https://doi.org/10.2478/ctra-2025-0006

Neville, M. (2024). Relationship of Cognition to Creativity. In G. I. Hersch, M. S. Coffey & N. Lamport (Eds.), *Creative Engagement in Occupation* (pp. 41-48): Routledge.

Organisation for Economic Co-operation and Development [OECD]. (2019). An OECD learning framework 2030. In G. Bast, E. G. Carayannis, & D. F. J. Campbell (Eds.), *The future of education and labor* (pp. 23-35). Springer.

Parlak, S., Tokel, N., & Çakiroğlu, Ü. (2024). Reverse engineering in robotics classrooms: boosting creative thinking and problem solving. *International Journal of Computer Science Education in Schools*, *7*(1), 227. https://doi.org/10.21585/ijcses.v7i1.227

Plucker, J. A. (2021). *Creativity and innovation: Theory, research, and practice*. Routledge.

Rhodes, M. (1961). An analysis of creativity. *The Phi delta kappan, 42*(7), 305-310.

Rui, C. (2022). The Construction of "Reverse Engineering" Teaching Model in Science Teaching. *Teaching & Administration, 20*, 62-64.

Samaniego, M., Usca, N., Salguero, J., & Quevedo, W. (2024). Creative thinking in art and design education: A systematic review. *Education Sciences, 14*(2), 192. https://doi.org/10.3390/educsci14020192

Schut, A., Klapwijk, R., Gielen, M., Van Doorn, F., & De Vries, M. (2020). Uncovering early indicators of fixation during the concept development state of children's design processes. *International Journal of Technology and Design Education*, *30*(5), 951‑972. https://doi.org/10.1007/s10798-019-09528-2

Singaporean Ministry of Education. (2015). 21st century competencies. https://www.moe.gov.sg/education-in-sg/21st-century-competencies

Sternberg, S. (2011). Modular processes in mind and brain. *Cognitive neuropsychology*, 28(3-4), 156-208. https://doi.org/10.1080/02643294.2011.557231

Tan, L., Chai, C. S., Deng, F., Zheng, C. P., & Drajati, N. A. (2019). Examining pre-service teachers' knowledge of teaching multimodal literacies: A validation of a TPACK survey. *Educational Media International, 56*(4), 285-299. https://doi.org/10.1080/09523987.2019.1681110

Tierney, P., & Farmer, S. M. (2002). Creative self-efficacy: Its potential antecedents and relationship to creative performance. *Academy of Management Journal, 45*(6), 1137-1148. https://doi.org/10.5465/3069429

Torrance, E. P. (1966). *Torrance tests of creative thinking*. APA PsycTests. https://doi.org/10.1037/t05532-000

Trickett, E. J., & Moos, R. H. (1974). Personal correlates of contrasting environments: Student satisfactions in high school classrooms. *American Journal of Community Psychology, 2*(1), 1. https://doi.org/10.1007/BF00894149

Üret, A., & Ceylan, R. (2021). Exploring the effectiveness of STEM education on the creativity of 5-year-old kindergarten children. *European Early Childhood Education Research Journal, 29*(6), 842-855. https://doi.org/10.1080/1350293X.2021.1913204

Van Hooijdonk, M., Mainhard, T., Kroesbergen, E. H., & van Tartwijk, J. (2020). Creative problem solving in primary education: Exploring the role of fact finding, problem finding, and solution finding across tasks. *Thinking Skills and Creativity*, 37, 100665. https://doi.org/10.1016/j.tsc.2020.100665

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological process*. Harvard University Press.

Wang, A., & Burdina, G. (2024). Developing students' creative thinking using innovative education technologies. *Interactive Learning Environments, 32*(7), 3490-3500. https://doi.org/10.1080/10494820.2023.2184390

Wu, C. F. J., & Ding, Y. (1998). Construction of response surface designs for qualitative and quantitative factors. *Journal of Statistical Planning and Inference*, *71*(1-2), 331-348. https://doi.org/10.1016/S0378-3758(98)00003-2

Yang, J. (2022). *Research on design and practice of robotic programming learning activities from the perspective of reverse engineering* [Unpublished master's thesis]. Northwest Normal University.

You, J. W. (2021). Investigating the effects of achievement goals on team creativity and team achievement in learning communities at a South Korean university. *Higher Education, 81*(2), 367-383. https://doi.org/10.1007/s10734-020-00545-y

Yuan, Q. (2023). Thinking-driven teaching design of cryptographic software reverse engineering. *Computer Education, 11*, 14. https://doi.org/10.16512/j.cnki.jsjjy.2023.11.014

Zadorozhnyy, A., & Lee, J. S. (2025). Informal digital learning of English and willingness to communicate in a second language: Self-efficacy beliefs as a mediator. *Computer Assisted Language Learning*, *38*(4), 669-689. https://doi.org/10.1080/09588221.2023.2215279

Zhan, Z., Tu, K., Yang, H., Gao, S., & Zou, X. (2024). Effect of reverse engineering pedagogy on students' learning performance, cultural heritage literacy, and creativity in a paper sculpture C-STEAM course. *Journal of Educational Technology Development Exchange, 17*(2), 153-174. https://doi.org/10.18785/jetde.1702.07

Zhang, M. (2024). *Practical research on cultivating primary school students' micro-innovation ability based on reverse engineering method — Take the "3D printing" as an example* [Unpublished master's thesis]. Guizhou Normal University.

Zhong, B., Kang, S., & Zhan, Z. (2021). Investigating the effect of reverse engineering pedagogy in K-12 robotics education. *Computer Applications in Engineering Education, 29*(5), 1097-1111. https://doi.org/10.1002/cae.22363

Zhong, B., Liu, X., & Li, X. (2024). Effects of reverse engineering pedagogy on students' learning performance in STEM education: The bridge-design project as an example. *Heliyon, 10*(2), e24278. https://doi.org/10.1016/j.heliyon.2024.e24278